Energetics

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Outline

A bit about technological revolutions

Introduction to some the candidates

In depth look at one specific technology

Ramifications

New missions and opportunities

Impact on aviation design & optimization

Disruptive Technology

- Innovations and advances in technology are always disruptive on some scale.
- This is similar to Earthquakes
  - Small quakes impact the local area
  - Large quakes are felt globally and forever change the landscape
- Advances in Technology
  - Small advances may change an industry
  - Large advances can change the world, create new industries, and destroy old ones

Fortune favors those who are prepared!

Predictability

- Continuing the analogy, We can predict advances in technology about as well as earthquakes

- With some study of the forces at play (tectonic vs “market”) and some knowledge of where change can occur (faults vs research areas) you can begin to develop a probabilistic sense of what might happen and when.

- The specifics quickly become less predictable the further out you look, but looking far ahead can be fruitful.

Energetics Revolution is Likely

There is a tremendous need globally to develop alternative energy sources to fuel continued economic growth in developing nations and due to the threats of global warming, peak oil, and geopolitics. The need appears insatiable.

Aside from the relatively incremental technologies that are chemical-like in their economics and energetics, there are several truly revolutionary ones being researched that significantly increase the probability that at least one major advance is likely in the next 20 years or so.

Candidates

Wide range of methods considered in order to cover the wide range of applications

- Transmitted or Beamed power
- Novel forms of stored energy
- Nuclear & Beyond

- Not going to talk about PhotoVoltaics or electrical storage methods. Also will not talk about “normal” chemical power like algae.

Beamed Power

Overview: Power provided by transmitting energy to vehicle - usually in the form of microwaves or lasers.

Potential Impact: 1x times chemical, Low power, niche market, significant infrastructure required for high power or long distance applications.

Status: Technology being refined,

Technical challenge: System efficiency, conversion on both ends, beam formation & tracking, …

Energy Storage Methods

Overview: Compounds that must be made …

- Metallic Hydrogen (20x)
- Inner-electron chemical bonds (10x-100x)
- SBER (remotely related) (100x)

Potential Impact: ~10^2x chemical, somewhat scalable, clean, relies on other energy sources

Status: First two - theoretical, Last - experimental

Technical challenge: Fabrication, stability/safety, systems design

Hot and Anetronic Fusion

Overview: Variations on nuclear fusion -

Hot Light element fusion (D+D or D+T)

Aneutronic e.g., $p+{}^{11}B > 3\ {}^{4}He + 8.7MeV$

Potential Impact: 10^6x chemical, large scale, high power, could be 'clean'

Status: Long history of theoretical and experimental development. New approaches!

Technical challenge: Maintaining p, T and confinement. Getting significant (>1) power gain. Thrust to weight. Scalability

Antimatter

Overview: 100% $E=mc^2$ Matter in - Photons out
Most practical form is positronium yielding two 0.511MeV gamma rays

Potential Impact: 10^9x chemical. Clean, scalable, mass critical applications. This is really just another energy storage method.

Status: Useful storage methods developing rapidly

Technical challenge: Storage lifetime, cost effective production/capture

Zero Point Energy

Overview: Immense energy source predicted by quantum physics. Best known manifestation is the Casimir force.

Potential Impact: 10^{105}x chemical! Clean.

Status: Recent advances in modeling the Casimir effect - no shortage of conceptual manifestations

Technical challenge: Further improvements in theory, fabrication, scalability, materials, other ways to ‘rectify the quantum foam’.

Low Energy Nuclear Reactions

Overview: A form of nuclear power based on the Weak Force

Potential Impact: 10^6x chemical, very scalable, clean, perhaps the most disruptive technology - a magnitude 10 TechnoQuake!

Status: Increasingly active area of research. Mostly experimental with recent theoretical advances.

Technical challenge: Better/more complete theory

LENR History

- Begins in the 1890's, Rutherford and Thompson experimenting with elemental transmutation
- 1922 Wendt & Irion work with exploding wires
- 1989 Pons & Fleischmann announce Cold Fusion from an electrochemical cell containing PdD
- Physics community promptly discredit the claim
- The problem was their attribution to D-D fusion
  - Energetics of overcoming the Coulomb barrier
  - High energy neutrons not observed
- P&F experiment did produce excess heat and He
- Difficult to reproduce, experiments took 100 days

LENR since P&F

- Today, there are many groups around the world working on LENR, 20+ in the US alone.
- Abundant evidence for excess heat and element transmutation with both Deuterium and Hydrogen metal hydrides with increased reproducibility
- Wide range of successful experimental methodologies (PdD, NiH, liquid & gas phase, …)
- Nearly every group has developed their own theory (all requiring “New Physics” or Miracles)
- All theories are based on the Strong Nuclear force and are variants of Cold Fusion
- … except for one new theory

Widom-Larsen Theory

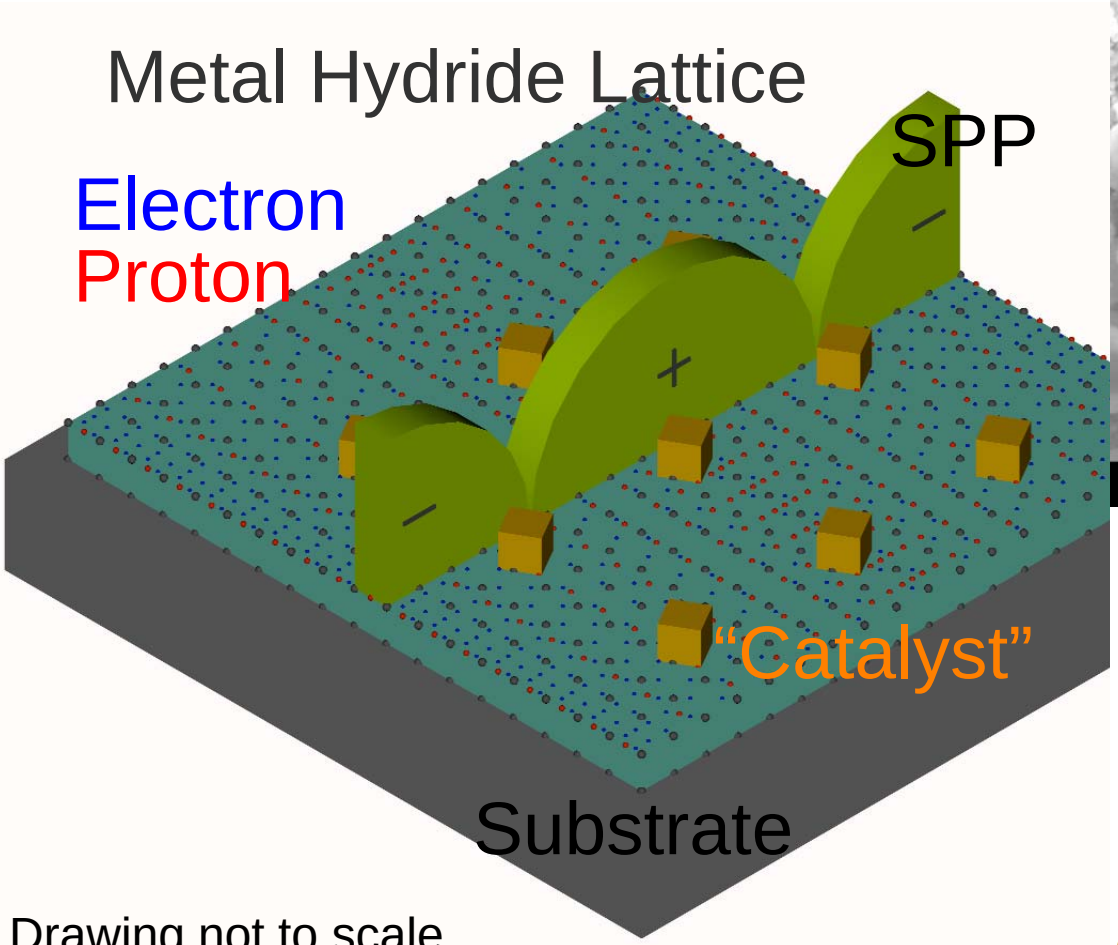
- Lewis G. Larsen developed a theory of LENRs (WLT) that explains ALL the evidence and along with Dr. Alan Widom published their theory in Eur. Phys. J. C (2006)
- WLT is 1st theory to not require “New Physics”.
- It relies on the Weak Nuclear force which:
  - Produces a neutron via electron capture
  - Does not have a Coulomb barrier to overcome
- The theory combines QED, Condensed Matter, Nuclear, and Plasma Physics

LENR IS NOT “COLD FUSION”

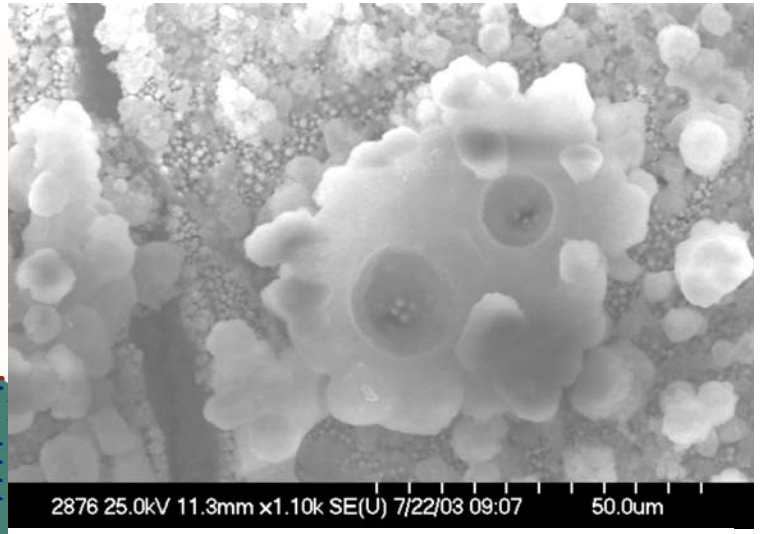
WLT Overview

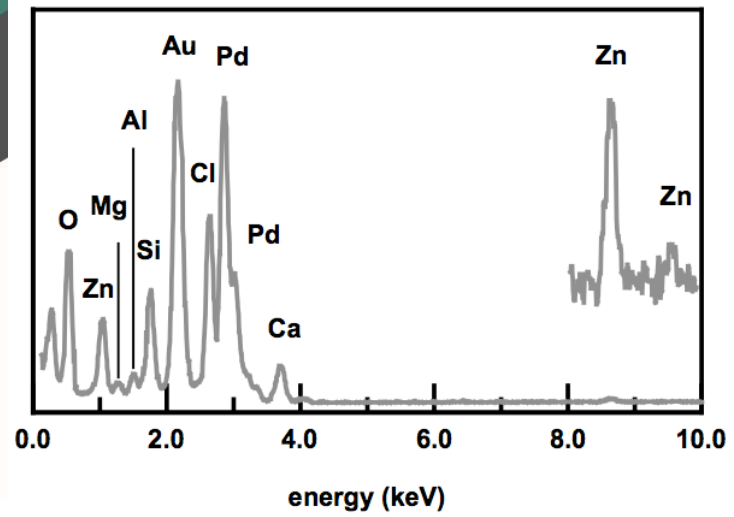
- $p + e^* \Rightarrow n + \bar{\upsilon}_e$ Inhibited by 0.78MeV
- e* is a “heavy electron” allowed by QED - requires high electric fields (~10^{11}V/m or 10V/Å)
- High fields result from a breakdown of the Born-Oppenheimer Approximation via a coupling of Surface Plasmon Polaritons to a collective proton resonance in the metal hydride.
- The result is an Ultra Low Momentum Neutron which is rapidly absorbed by nearby nuclei.
- Subsequent decays release significant energy.
- Select impurities/catalysts determine the overall energetics

Diagram, Image, and Data



Drawing not to scale





WLT Energetics

- An example of the Li-Be-He cycle energetics
  - $p + e^* \Rightarrow n + \bar{\upsilon}_e$ Inhibited: 0.78MeV x6 = ~5MeV
  - $^6Li + n \Rightarrow {}^7Li$
  - $^7Li + n \Rightarrow {}^8Li$
  - $^8Li \Rightarrow {}^8Be + \beta + \upsilon_e$
  - $^8Be \Rightarrow {}^4He + {}^4He$ ~27MeV released to this point
  - $^4He + n \Rightarrow {}^5He$ This cycle runs twice
  - $^5He + n \Rightarrow {}^6He$
  - $^6He \Rightarrow {}^6Li + \beta + \upsilon_e$ ~3MeV x2 released here
- In this cycle 6 protons and 3 electrons are converted to a ^6Li and 9 (anti)neutrinos with a net release of ~28MeV (other cycles exist)

Energy Density Comparison

- Fission - Strong nuclear force - 3% Efficient
  - $^{235}U + n \Rightarrow {}^{92}Kr + {}^{141}Ba + n + n + \sim 200MeV$
  - 88 GJ/g or 1,900,000 times chemical
- Fusion - Strong nuclear force - ~5% Efficient
  - $^{2}H + {}^{3}H \Rightarrow {}^{4}He + n + \sim 18MeV$
  - $^{2}H + {}^{2}H \Rightarrow {}^{3}H + p + \sim 4MeV$
  - or $\Rightarrow {}^{3}He + n + \sim 3MeV$
  - 337 GJ/g or 7,300,000 times chemical
- LENRs - Weak nuclear force - TBD% Efficient
  - $6p + 3e \Rightarrow {}^{6}Li + 6\ \bar{\upsilon}_e + 3\ \upsilon_e + 28MeV$
  - ~370 GJ/g or **<u>8,000,000 times chemical!</u>**
  - W-L conservative estimate - 4,000 times chemical

Ramifications

- Nuclear-like energy densities **Scalable** from mW to GW
- Little or no need for radiation shielding - **Portable**
  - Adaptable to the full range of transportation systems
  - Wholly obviates the reasons (weight, safety, attendant costs) fission is not used
- **Revolutionizes Aviation and Access to Space**
  - No GHG (CO_2, H_2O, aerosols, …) concerns
  - Decouples energetics from reaction mass
  - Fuel mass essentially goes away for air-breathing applications, reduces total mass
  - Fuel is very cheap (e.g., electrolysis of H_2O, waste PAHs, …)
- **Total replacement of fossil fuels** for everything but synthetic organic chemistry

Impact to Aviation

A revolutionary breakthrough in energetics would impact commercial, military, and civilian/personal aviation by:

- Altering the current metrics for design optimization
- Creating new missions and markets

Design Metrics

- Fuel mass and volume are negligible:
  - Mass is essentially constant from take-off to landing
  - Increase in payload as percentage of TOW
  - Optimizations for increased landing weight
- Increase in performance
  - Energetics favorable for supersonic cruise
  - Greatly extended range/capacity for rotorcraft
- Overall reduction in mass opens up the micro and nano vehicle design space

New Missions

- Increase in capability results in new applications
  - Mini - Micro - Nano air vehicles
    - Sensor swarms/meshes
    - Package delivery
    - Huge implications for ATC
  - Personal Air Vehicles
    - Performance equates to increased safety
    - Performance fully enables true point-to-point
    - Greatly extended range (Local -> Global!)
    - Huge implications for ATC
  - Military
    - Unlimited loiter
    - Enhanced mobility with a reduction of supply logistics
    - Horizontal take-off access to orbit